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# ASSESSING AND IMPROVING COMMONALITY AND DIVERSITY WITHIN A PRODUCT FAMILY

**Fabrice Alizon and Steven B. Shooter**
Bucknell University
Lewisburg, PA 17837

**Timothy W. Simpson**
The Pennsylvania State University
University Park, PA 16802

## ABSTRACT

At a time when product differentiation is a major indicator of success in the global market, each company is looking to offer competitive and highly differentiated products. This differentiation issue is restricted by the design of platform-based products that share modules and/or components. It is not easy to differentiate products in a market that is often overwhelmed by numerous options. A platform-based approach can be risky because competition in the global market can become an internal competition among similar products within the family if there is not enough differentiation in the family. Thus, the goal for the product platform is to share elements for common functions and to differentiate each product in the family by satisfying different targeted needs. To assess commonality in the family, numerous indices have been proposed in the literature. Nevertheless, existing indices focus on commonality and reflect an increase in value when commonality increases but do not positively reflect an increase in the value as a result of diversity; hence, the *Commonality versus Diversity Index* (CDI) is introduced in this paper to assess the commonality and diversity within a family of products or across families. The CDI has variable levels of depth analysis to help designers design or improve the product family. Two case studies using single-use cameras and power tool families highlight the usefulness of this new index.

**Keywords**: commonality, diversity, variety, product family, product platform

## 1. INTRODUCTION

In today's global market, customers are surrounded by many products, sometimes satisfying the same needs and with similar industrial design. As a result, companies look for both differentiation in their products and low design and manufacturing costs to improve their competitiveness. A platform-based design approach partially responds to these issues by promoting sharing of modules, components, and/or manufacturing process to reduce the cost of each product, but the reduction of cost and the increase in differentiation are competing objectives. Cost reduction using a product platform encourages common components while differentiation requires different components to satisfy each market niche. Thus, one of the dangers of platform-based development is to sacrifice diversity, instead designing low cost products with similar features and industrial design. Therefore, one of the main issues during platform design is to ensure sufficient differentiation within the family of products without exceeding the budget; however, existing commonality indices (see Section 2) reflect an increase in value when commonality increases, but they do not positively reflect an increase in the value as a result of diversity. Thus, this study focuses on a richer treatment of commonality and diversity within a product family to help designers identify what needs to be common and what does not.

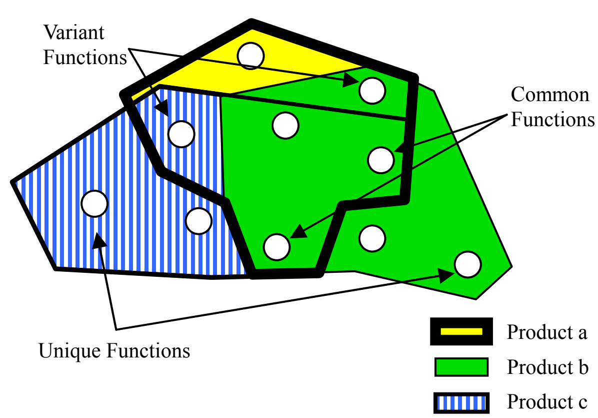


**Figure 1. Illustration of a product family sharing functions**

Figure 1 illustrates the sharing of components within a family of products. In this figure, common functions are the same for all products, variant functions are the same but the

[1] Please address all correspondences to shooter@bucknell.edu.

attributes are different, and unique functions are specific to an individual product. The goal is: (1) common functionality should use common components, (2) unique function(s) should use unique component(s), and (3) variant function(s) should use variant component(s), in the same proportion.

Section 2 presents an overview of related research. The Commonality versus Diversity Index (CDI) is introduced in Section 3. The CDI is then demonstrated using two cases studies (single-use camera and power tools) in Section 4. The improvement of the product family design using the results of the CDI is discussed in Section 5. Section 6 gives closing remarks and future work.

## 2. RELATED RESEARCH

Commonality and standardization of a product platform are the main issues in the design of a product family. Wheelwright and Clark [1] recommend specifying platform-based products that are able to satisfy the needs of the core group of customers and easily create derivatives through the addition, substitution, and removal of features. De Lit and Delchambre [2] describe how to use common components to reduce the lead-time and cost in product development and manufacturing processes. Commonality is assessed by several indices, taking into account different criteria such as components, materials, connections, etc. More accurate indices have also been suggested, which take into account cost and the importance of each product to the customer. The Degree of Commonality Index (DCI) introduced by Collier [3] is a ratio between the number of common components and the total number of components in the family. But when the family is redesigned it is difficult to assess the improvement in the family because the index does not have fixed boundaries. The Total Constant Commonality Index (TTCI), introduced by Wacker and Trevelan [4], has fixed boundaries (0-1). This index can be used to assess different product families, but it does not consider the cost of components. The Commonality Index (CI) introduced by Martin and Ishii [5], is similar to Collier's index, adding variety and using point of product differentiation and set-up costs. The Component Part Commonality Index from Jiao and Tseng [6] is an extension of the DCI, which adds process commonality to component commonality; however, the type of materials and the manufacturing process are not taking into account. The Product Line Commonality Index (PCI) is the most evaluative of the aforementioned indices because the PCI is based on the notion that a non-differentiating component should be common, not just a ratio between common and total number of components [7]. PCI also considers the criteria of size, shape, materials manufacturing process, assembly, and fastening schemes. Pandit and Siddique [8] propose three indices—component commonality, connection commonality, and assembly commonality—to obtain an overall assessment of the commonality where each index can have a different weight. The Generational Variety Index introduced by Martin and Ishii [9] integrates the product life cycle to predict which component might be changed to meet future market requirements. They also developed a Coupling Index to quantify the relationship between current and prospective components. A functional similarity index was presented to help designers in the conceptual design stage [10,11]. More recently, the Comprehensive Metrics for Evaluating Commonality index (CMC) was presented by Thevenot and Simpson [12]. This index takes into account more criteria for each component to better assess the importance of commonality for each component with fixed boundaries. Several indices that assess the degree of variation within a scale-based product family have also been proposed by [13-15]. Finally, Erni and Lewerentz [16] proposed a set of multi-metric indices that represent high-level characteristics (features, commonality, etc.) and several low-level characteristics. A more detailed comparison of these indices is given by Thevenot and Simpson [17].

Such indices are helpful for designers to manage the complex design of a product platform; however, no one has fully considered the necessary tradeoff between commonality and diversity within an index for product family design. The main criterion that is taken into account in these studies is the commonality, but they do not increase the score when the component embodies necessary diversity as described by, for example, Pine [18] and Meyer and Lehnerd [19]. The advantage of the CDI introduced in the next section is its ability to assess market requirements, including commonality and diversity as represented by the core group of customers and their variants.

## 3. COMMONALITY AND DIVERSITY INDEX

The Commonality versus Diversity Index (CDI) scores both the commonality and diversity within a product family that satisfies different needs by providing different functionalities that mandate different components. Some of the components are common for all members of the family, some are variant (i.e., adapted to some of the products), and some are unique. The aim of this index is to help indicate what should be made common and what should be different within the family.

### 3.1. Definition

#### 3.1.1 Domain of Study

This index is computed for an existing family of products and can be used in product development during the early stages of a project. This index is based on the comparison of components referring to a function(s), e.g., *view the scene* in the case of a camera. Each product in the family can be represented by a graph that links functions and components (see Figure 3 in Section 4). Merging graphs of all the resulting products gives the functions and the associated components across the family. Afterward, designers group components to take into account the common/variant/unique aspect because for a given function some products need the same components while others do not. In the camera example shown in Table 1, the component Cam is "*common*", the Structure is "*variant*", and the external casing is "*unique*" for the Camera 3.

**Table 1: Illustration of a common variant and unique component**

| Component | Camera 1 | Camera 2 | Camera 3 | Comment |
|---|---|---|---|---|
| Cam |  |  |  | Common |
| Structure |  |  |  | Variant |
| Lens (Zoom) | - | - |  | Unique |

The computation of the CDI is based on the existing set of common or specific (variant or unique) components within the product family and the "ideal" tradeoff between commonality and diversity based on the functional requirements for the family. Practically, this ideal tradeoff is based on the value of the design requirements specified from market analysis (based on the given market segmentation). This index is scored from 0 to 1, where 1 indicates a perfect utilization of the commonality-diversity and 0 indicates a failure to do so.

The aim in this index is to score the commonality-diversity for each component of each function. Table 2 gives an example for a given function and component for a family of 8 products. The challenge is to assess the commonality versus diversity between the ideal and actual commonality in a manner similar to the ideal minimum number of parts in Boothroyd's and Dewhurst's DFA analysis [20].

**Table 2. Example of comparison of commonality versus diversity between ideal and actual design**

| Functions | Products | Component 1 *Actual* | Component 1 *Ideal* |
|---|---|---|---|
| Function 1 | Product 1 | Φ | O |
| | Product 2 | O | O |
| | Product 3 | Θ | O |
| | Product 4 | Δ | Δ |
| | Product 5 | ☐ | ☐ |
| | Product 6 | ☐ | ☐ |
| | Product 7 | ☐ | ☐ |
| | Product 8 | ☐ | ☐ |

In this example, Component 1 has three physical representations (O, Δ, and ☐): O is ideally common across three products, Δ is ideally specific to Product 4, and ☐ is ideally common for the rest of the products. The sub-groups are specified based on the number of platforms (one sub-group per platform). In fact, each platform can have a different group of common components, and this will be not penalized. Sub-groups are created to isolate those that need to be common and/or specific in their own sub-group. In Table 2, there are two sub-groups: the first includes (O and Δ) and the second includes (☐). If there is only one platform or if all platforms share the same common components, then there is only one sub-group.

The CDI is computed for each sub-group of products and then an aggregate is formed for all the sub-groups that include all the components for that function that define the CDI score for that function. Finally, the CDI score of all the functions is aggregated to obtain the CDI score for the family.

### 3.1.2 Mathematical Definition

Let $\mathscr{P} = (P_1, \ldots, P_N)$ be a family of $N$ products that has $F$ functions $f_i$ ($i$=1 to $F$). Let $f_i$ be a given function in the product family where $f_i$ is achieved by a set of components. For example, in a single-use camera (the product), the function *view the scene* is achieved by components such as the *view finder*.

Denote $c_{ik}$ ($k$=1 to $K$) the components for this function $f_i$ . Given $k$, $c_{ik}$ refers to the generic component (e.g., *view finder*). The physical representations or instances of this generic component in the products $P_1 \ldots P_N$ are denoted $c^j_{ik}$, for $j=1...N$. By agreement, we say that $c^j_{ik}$ =*null* if the component $c_{ik}$ is not present (has no instance) in product $j$.

Example: $c_{ik}$ = *viewfinder* (generic component):
$c^1_{ik}$ = the viewfinder of camera n°1.
$c^2_{ik}$ = the viewfinder of camera n°2, etc.

For each generic component $c_{ik}$ of the function $i$, we define sub-groups of the product family. These sub-groups correspond to the number of platforms within the family, because a platform has common components, which can be different from one sub-group to the next. Thus, for each component $c_{ik}$ there are $G_{ik}$ sub-groups: $g_m$, $l=1...G_{ik}$.

In each sub-group $g_m$, there is commonality and diversity specified by marketers such that the final design meets or does not meet these specifications. Hence we speak of allowed diversity and non-allowed commonality-diversity that is specified for components. The "non-allowed commonality" corresponds to specific components that should not be common, and "non-allowed diversity" refers to common components that should not be specific. This "non_allowed_com_div" depends on $i$, $k$, and the sub-group $g_m$:

Let $c^j_{ik}$ = the ideal instance and $c'^j_{ik}$ = the actual instance of component $k$ in product $j$. For common components we define the indicator function:

$$\mathbb{1}\left\{c^j_{ik} \neq c'^j_{ik}\right\} = 1 \text{ if } c^j_{ik} \neq c'^j_{ik} \text{ and } 0 \text{ otherwise.}$$

In the same way, we define for specific components the indicator function:

$$\mathbb{1}\left\{c_{ik}^{j} = c'^{j}_{ik}\right\} = 1 \text{ if } c_{ik}^{j} = c'^{j}_{ik} \text{ and } 0 \text{ otherwise.}$$

Thus, the "*non_allowed_com_div*" of a given sub-group is equal to the sum of both indicator functions for all the components in the sub-group:

$$non\_allowed\_com\_div_{ikg_m} = \sum_{P_{j\in P\cap g_m}} \mathbb{1}\left\{c_{ik}^{j} \neq c'^{j}_{ik}\right\} + \sum_{P_{j\in P\cap g_m}} \mathbb{1}\left\{c_{ik}^{j} = c'^{j}_{ik}\right\}$$

where in the first sum, we take only common components into account, and in the second sum, we consider only specific components.

For each generic component $c_{ik}$ there is an ideal maximum diversity in the sub-group $g_m$, denoted by maximum $div_{ik}^{g_m}$, which is equal to the number of elements in the sub-group - 1. The score of the generic component $c_{ik}$ of function $i$ within the sub-group $g_m$ is then:

$$CDI_{sub-group\ m} = 1 - \frac{non\_allowed\_com\_div_{ikg_m}}{\max\ div_{ikg_m}}$$

This score on the set of sub-groups is the average:

$$CDI_{Component\ k} = \frac{1}{G_{ik}} \sum_{m=1}^{G_{ik}} \left(1 - \frac{non\_allowed\_com\_div_{ikg_m}}{\max\ div_{ikg_m}}\right) \quad (1)$$

This score on the set of generic components is the average score of the function $f_i$:

$$CDI_{Function\ i} = \frac{1}{K_{ij}} \sum_{k=1}^{K_{ij}} \frac{1}{G_{ik}} \sum_{m=1}^{G_{ik}} \left(1 - \frac{non\_allowed\_com\_div_{ikg_m}}{\max\ div_{ikg_m}}\right) \quad (2)$$

Then the overall score for the family of products $\mathscr{P}$ is:

$$CDI_{Family\ P} = \frac{1}{F} \sum_{i=1}^{F} \frac{1}{K_{ij}} \sum_{k=1}^{K_{ij}} \frac{1}{G_{ik}} \sum_{m=1}^{G_{ik}} \left(1 - \frac{non\_allowed\_com\_div_{ikg_m}}{\max\ div_{ikg_m}}\right) \quad (3)$$

### 3.2. Example

To describe in detail CDI's computation, an example is given in Table 3 (with only one sub-group). All the cameras are listed for this function. This example focuses on the *view finder* component with the actual and ideal groups of components and is composed of two groups of components:

1. The ideal *common* group for the cameras: Plus Digital, Max HD, Max HQ, W&S, Power Flash, B&W, and Fun Saver Outdoor,
2. The ideal *variant* group including the Zoom and the Advantix cameras, represented by the shaded rows.

Thus $G_{display\ information\text{-}viewfinder} = 2$. The total number of components for this function is equal to 10. The *ideal common group* is specified by designers who assess whether the component should or should not be common. If the function is the same and the design requirements are the same, then there is no reason to have a different component. The diversity of the *view finder* is scored as follows. The first camera in this group (Plus Digital) is given a datum value of 1 in the case "existing group". For the next camera (Max HD), if the *view finder* is the same as the Plus Digital camera, then the number is still 1; if not, the number is 2, and so on for all the cameras to obtain the diversity across the family for this component. The diversity value of 2 is equal to the total number of allowed different components. The maximum diversity for the common group is computed the same way (8-1) = 7. The actual diversity is (4-1) = 3. Then applying the CDI for this group of components, the result is: 1-(3/7) = 0.57. For the second group, the variance is intended; so, the score is equal to 1. The overall score is found using Eq. 1: (0.57*8+1*2)/10 = 0.66. For the non-allowed commonality (when there is commonality, but the component should be specific), the process is exactly the same.

**Table 3. Example of a CDI score for the *Display Information* function for the *view finder* component.**

| Camera/Components | Actual Instance | Ideal Instance |
|---|---|---|
| **Zoom** | Variant | Variant |
| **Plus Digital** | 1 | Common |
| **Max HD** | 2 | Common |
| **Max HQ** | 2 | Common |
| **W&S** | 3 | Common |
| **Power Flash** | 2 | Common |
| **Advantix** | Variant | Variant |
| **B&W** | 1 | Common |
| **Fun Saver** | 4 | Common |
| **Outdoor** | 2 | Common |
| **Score** | **0.66** | |

If the component is used by several functions, the choice is made to score components for all functions. These components are normalized afterward and finally aggregated to obtain the overall score of the CDI for the whole family. To obtain the CDI score by function, the scores of all components are normalized for this given function. This helps designers to identify which function has a bad score and focus on it. The family score is obtained by balancing the CDI of each function for every product, allowing designers to balance the commonality and diversity in the family. One of the strengths of the CDI is its ability to analyze the commonality-diversity with variable depth of analysis by computing $CDI_{component}$, $CDI_{function}$, and $CDI_{family}$. Then potential improvements can be highlighted at all three levels of analysis.

## 4. CASE STUDY

Two case studies are presented to demonstrate and validate the usefulness of CDI: a family of single-use cameras and three families of power tools. The Kodak® single-use cameras, used for the first study and the Black & Decker tool sets used for the second are two well-known families readily available in the market. Because Black & Decker produces several families, this second study integrates a horizontal and a vertical assessment (across products within each family and across families).

### 4.1 Single-Use Camera Family

The Kodak® single-use cameras shown in Figure 2 is used. An example of a functional decomposition resulting from dissection of these 10 cameras is presented in Figure 3. For example, the function *display information* for camera 1 uses three components: the *counter wheel*, the *flash information*, and the *view finder*.

**Figure 2. Single-use camera family, from left to right: Zoom, ADVANTIX Switchable, Black & White, Fun Saver Flash, Max High Definition, Max HQ Maximum Versatility, Max Outdoor, Plus Digital, Max Power, Water & Sport**

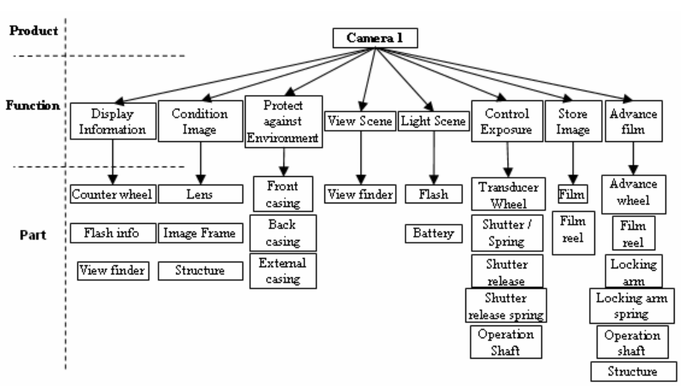


**Figure 3. Functional decomposition of a camera**

Table 4 and Table 5 present functions that are listed in the far left column followed by camera models. In these tables, the shaded boxes correspond to an allowed diversity (summarized at the top of the table with the % diversity allowed for a given component). Components and their diversity assessment value are listed across the top for each camera. The CDI score is computed, using Eq. 3, for each function. In this example, the CDI of the *light the scene* function has the maximum with a score of 1, unlike the *display information* function, which is scored as 0.62. In this example the percentage on top of each column is the percentage of intended diversity for this given component specified by designers or marketers. The shaded rows indicate the intended diversity.

**Table 4. Example of data entered for the single-use camera family with the maximum score for the CDI**

| Function | Component | Flash (CB) | Battery |
|---|---|---|---|
| | Cameras \ Diversity | 70% | 50% |
| Light the Scene | Zoom | 1 | 1 |
| | Plus digital | 2 | 2 |
| | HD | 3 | 1 |
| | HQ | 1 | 1 |
| | W&S | - | - |
| | Power flash | 1 | 1 |
| | Advantix | 4 | 3 |
| | B&W | 5 | 2 |
| | Fun saver | 6 | 1 |
| | Outdoor | - | - |
| Score | 1.00 | 1.00 | 1.00 |

**Table 5. Example of data entered for the single-use camera family with a medium score of the CDI**

| Function | Component | Counter Wheel | View Finder | Flash info (CB) |
|---|---|---|---|---|
| | Cameras\ Diversity | 0% | 20% | 20% |
| Display Information | Zoom | 1 | 6 | 1 |
| | Plus digital | 2 | 2 | 2 |
| | HD | 1 | 1 | 1 |
| | HQ | 1 | 1 | 1 |
| | W&S | 2 | 3 | - |
| | Power flash | 3 | 1 | 1 |
| | Advantix | 4 | 5 | 4 |
| | B&W | 2 | 2 | 2 |
| | Fun saver | 3 | 4 | 3 |
| | Outdoor | 5 | 1 | - |
| Score | 0.62 | 0.56 | 0.66 | 0.66 |

The final CDI score for the entire single-use camera family is 0.80, which is a good score compared to a maximum potential of 1. The score for each function is given in Table 6. The function *view the scene* has the worst score with 0.43, and functions *light the scene* and *differentiate products* have the best score with 1.

For the same family, the corresponding PCI score is 51.8 (see Annex A). To compare the PCI (scored from 0 to 100) with the CDI (scored from 0 to 1), the PCI is normalized and is equal to 0.518. Thus, the difference between the PCI and the CDI score of 0.80 is explained by the consideration of variety. In effect, despite the fact that PCI is the only index that does not penalize differentiating (unique) components, the PCI considers variant components should be common while CDI considers variant components as a category of component to ensure diversity among the final products. Also PCI will only be 1 if a component is the same in all products whereas a CDI score of 1 is achieved if a component is common/variant/unique as it should be, leading to a higher overall score for the family.

The other indices in the literature only work at the family level and do not have this variability of depth analysis that the CDI allows at (1) the family level to assess if the family correctly respects the commonality-diversity and (2) the function level to asses if each function also assesses this ratio. This enables checking of strengths and weakness of family → products → functions as described in the next section.

**Table 6. CDI results for each function**

| Function | CDI Score |
|---|---|
| Display Information | 0.62 |
| Condition Image | 0.74 |
| Differentiate Products | 1 |
| Protect Against Environment | 0.49 |
| View Scene | 0.43 |
| Light Scene | 1 |
| Control Exposure | 0.73 |
| Store Image | 0.72 |
| Advance Film | 0.77 |

### 4.2 Families of Power Tools

This second case study uses three power tool families from the same manufacturer to validate the CDI for multi-family products; these families are shown in the Figure 4. The CDI can be applied as it was done before to each family and also to all three families. This analysis includes both a horizontal analysis (between products within a family) and a vertical analysis (across families).

**Figure 4. (Left to right) Versapak® Combo, Black & Decker® Combo, and Firestorm® Combo**

Using the same approach, the three families were scored, and the results are given in Figure 5. The CDI for each family (vertical analysis) gives the following results: the Versapak family has a score of 0.87 (complete score given in Annex B), the Black & Decker family as a score of 0.81, and the Firestorm family has a score of 0.85. The CDI is also computed for each type of product when the number of products of a specific type is at least three. Because the CDI scores the family based on the relative commonality-diversity within the family, two products are insufficient to score commonality. As such, the reciprocating saws have a score of 0.69, drills 0.63, and flash lights 0.78. The higher the number of products is, the more accurate the results.

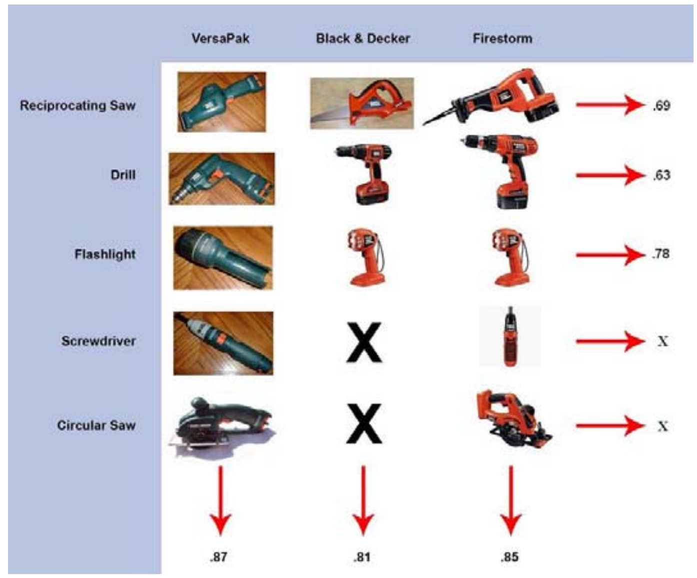


**Figure 5. Horizontal and vertical CDI for the power tools combo Versapak, B&D and Firestorm**

The CDI scores are also good compared to other studied products. The functional diversity within these families is more important than that in the single-use camera family. While the single-use cameras are quite similar, with only a few variations for the *protection against environment* function, film quality, etc., the power tool families provide significant different functionality such as drill, sander, saw, flashlight, etc. So, where classic indices will have to pre-screen the data to filter out all the specific components to avoid a non-representative and otherwise poor score (because of intended variety), the CDI integrates this necessary diversity and points to potential improvements. These improvements are discussed next.

### 5. IMPROVEMENT OF DESIGN BASED ON CDI

The target in this stage of analysis is to maximize the CDI score of each function in each product by looking at areas of low commonality-diversity. If the component can be the same, then the difference can be justified by a structural constraint (i.e., not enough room to fit the common component). Then it is easy for designers to discover if the resultant diversity is due to a structural constraint or just because the commonality-diversity has been estimated incorrectly. If it is a structural constraint, then it can be too costly to modify the existing design to have a common component. In effect, there usually is a strong relationship between the internal structure and the overall design and modifying this internal design can affect the overall design (new product). In this study the choice is made to ignore the internal structure and assume it cannot be modified—only small local modifications are allowed. Major modifications of the structure require information that this study does not consider, such as the cost of a major modification and whether that cost is justified.

So, if the CDI score is not equal to 1, then improvements are theoretically possible. Functions with at least one failure of the commonality-diversity ratio are checked for feasible commonality. Designers should ask: is it possible to improve commonality without impacting the overall structure? As a result, designers analyze all the functions, and each component is subject to an improvement or an explanation of the lack of commonality. For example, the function *display information* has a score of 0.62; thus, there is room for improvement. Part of this function, the *view exposure count* component is scored at 0.56 (see Table 7). After analysis, designers can realize that there is no reason for this component to be different and also that there is no overall structural constraint. We could make this component common across the entire family, which has the effect of increasing the CDI score for the component from 0.56 to 0.89. The design of the Advantix Switchable model is too constrained to improve the design of this *view exposure count* for this model to reach the score of 1.

**Table 7. CDI detailed for the *view exposure count***

| Function | Component | View exposure count diversity |
|---|---|---|
| | Cameras\ Diversity | 0% diversity |
| Condition Image | Zoom | 1 |
| | Plus digital | 2 |
| | HD | 1 |
| | HQ | 1 |
| | W&S | 2 |
| | Power flash | 3 |
| | Advantix | 4 |
| | B&W | 2 |
| | Fun saver | 3 |
| | Outdoor | 5 |
| | Score | 0.56 |

For the single-use cameras, the CDI score is 0.8 after improving each function by the previous process. The CDI score increases by 14% to 0.91 after 37 components were improved (right column of Table 8). This score is acceptable even though the goal remains 1.0. The improved score for each function is given in Table 8. The functions *protect against environment* and *control exposure* remain the same because the structure is too tightly constrained to improve the associated components.

For the power tool product families, the new CDI scores were computed based on improving variant components, and the results are 0.87, 0.81, and 0.85, respectively. Improvement analysis increased these scores by 15%, 12%, and 12%, respectively. The details are listed in Table 9 by function. The complete set of changes is listed in Annex C.

**Table 8. Improvement by function for the single-use cameras**

| Function | Before | After | Recommended Improvement |
|---|---|---|---|
| Display Information | 0.62 | 0.77 | Same *Counter Wheel* for all the cameras excepted the Advantix – *View finder* only different for the Water and Sport and the Fun Saver |
| Condition Image | 0.74 | 0.92 | Same *Image frame* except for the Advantix |
| Differentiate product | 1 | 1 | - |
| Protect against environment | 0.49 | 0.49 | - |
| View Scene | 0.43 | 0.77 | Same *View finder* only different for the Water and Sport and the Fun Saver |
| Light Scene | 1 | 1 | - |
| Control Exposure | 0.73 | 0.73 | - |
| Store Image | 0.72 | 1 | Same *Film reel* for all cameras |
| Score | 0.8 | 0.91 | |

**Table 9. Illustration of the improvement by function for the power tool families**

| Function | Versapak | | Black & Decker | | Firestorm | |
|---|---|---|---|---|---|---|
| | Before | After improvement | Before | After improvement | Before | After improvement |
| Provide Power | 0.84 | 1 | 0.83 | 1 | 0.73 | 1 |
| Convert EE-ME | 1 | 1 | 0.5 | 0.5 | 0.6 | 0.6 |
| Actuate EE | 0.58 | 1 | 0.15 | 0.75 | 0.47 | 1 |
| Transfer ME | 1 | 1 | 1 | 1 | 1 | 1 |
| Convert EE – Light | 1 | 1 | 1 | 1 | 1 | 1 |
| Convert EE – Sound | - | - | 1 | 1 | - | - |
| Import tool | 1 | 1 | 1 | 1 | 1 | 1 |
| Hold parts and Protect | 0.67 | 1 | 1 | 1 | 1 | 1 |
| Guide Solid | 1 | 1 | - | - | 1 | 1 |
| Score | 0.87 | 1 | 0.81 | 0.91 | 0.85 | 0.95 |

Regarding the vertical score of the CDI for the flashlight, drill, and reciprocating saw gives the values of 0.78, 0.63, and 0.69, respectively. The improvements in these three products are presented in Table 10 with the scores increased by 15%, 49%, and 29%, respectively. The components that can not be improved are the components that are too constrained by the original definition, such as the structure for the single-use cameras or the casing for the power tool.

**Table 10. Illustration of the improvement by function**

| Function | Flash light | | Drill | | Reciprocating saw | |
|---|---|---|---|---|---|---|
| | Before | After improvement | Before | After improvement | Before | After improvement |
| **Provide Power** | 0.67 | 1 | 1 | 1 | 1 | 1 |
| **Convert EE-ME** | - | - | 0.33 | 0.67 | 1 | 1 |
| **Actuate EE** | 0.75 | 1 | 0 | 1 | 0 | 0.75 |
| **Transfer ME** | - | - | 1 | 1 | 1 | 1 |
| **Convert EE – Light** | 1 | 1 | - | - | - | - |
| **Import tool** | 0.5 | 0.5 | 0.67 | 0.67 | 0.5 | 0.5 |
| **Hold parts and Protect** | 1 | 1 | 1 | 1 | 1 | 1 |
| **Guide Solid** | - | - | 1 | 1 | 1 | 1 |
| **Score** | **0.78** | **0.9** | **0.63** | **0.91** | **0.69** | **0.89** |

A major limiting factor for improving commonality is the structure. This will always be a problem when improving an existing product family because the configuration is already determined and can limit improvement by some structural constraints, unlike the original design, which is initially free of these constraints. So an extension of this study is to consider this method directly during the original design process, checking each function in terms of commonality/diversity, and adapting the structure to obtain a CDI of 1 for the whole family. This constraint highlights another difficulty, as the improvement is limited by structural constraints. The more constrained the structure is in the product family, the more difficult it is to improve the commonality-diversity in this family.

## 6. CLOSING REMARKS

The Commonality versus Diversity Index (CDI) has been introduced in this paper, and its context and computation have been defined. This new index is based on the component categories (common/variant/unique) and has fixed boundaries between 0 and 1. The CDI enables designers to penalize the score when the commonalty and the diversity are not respected regarding the specification of marketers. The CDI also manages to score the commonality-diversity when the family is composed of several different platforms. One of the other strengths of this new index is to allow different levels of analysis with the CDI of components, functions, and family when other indices address only family and component levels. The CDI then easily highlights where there is potential opportunity to improve the commonality-diversity in each level. This index works on existing products as well as a new design project. This new index was horizontally and vertically applied to two families of products. Both types of assessment allow different points of view across products within a family and across families. The result of these two case studies identifies the interest to apply this index to improve existing designs. As a consequence, an improvement based on these scores is proposed to enhance the commonality-diversity ratio within the family. These improvements do not consider the overall architecture of products in the family. Improvements significantly enhance the score of the CDI for single-use cameras by 14% and for power tools by 15% for the Versapak product family, 12% for the basic Black & Decker product family, and 12% for the Firestorm product family.

Future work will integrate the CDI in the early stages of design development. Because many decisions are made about the architecture and constraints during these stages, this integration will permit greater usability of the commonality/diversity ratio. Next steps will also include an optimization of the commonality-diversity within a product family based on several criteria such as cost, manufacturing, etc. This new index can be matched with the REUSE Method proposed by Alizon, et al. [21] to improve the identification of relevant designs and can also be included in the approach to design platform-based products introduced by Shooter, et al. [22]. Future models should also integrate higher architecture levels in products. Questioning the higher architecture level of the product (global structure) can significantly help designers to reach a higher CDI scores.

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## ANNEX A

### PCI FOR THE SINGLE-USE CAMERA

| Parts | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | ni | 1/ni^2 | Size & geometry f1 | Material & Manufacturing f2 | Fastening & assembly f3 | ni*f1*f2*f3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Counter wheel | 1 | 2 | 1 | 1 | 2 | 3 | 4 | 2 | 3 | 5 | 10 | 0.010 | 0.300 | 1.000 | 1.000 | 3.000 |
| View Finder | 6 | 2 | 1 | 1 | 3 | 1 | 5 | 2 | 4 | 1 | 10 | 0.010 | 0.400 | 1.000 | 1.000 | 4.000 |
| Flash Info | 1 | 2 | 1 | 1 | | 1 | 4 | 2 | 3 | | 8 | 0.016 | 0.500 | 1.000 | 1.000 | 4.000 |
| Lens | 2 | 1 | 1 | 1 | 1 | 3 | 4 | 1 | 5 | 3 | 10 | 0.010 | 0.500 | 1.000 | 1.000 | 5.000 |
| Image Frame | 2 | 1 | 3 | 3 | 1 | 4 | 5 | 1 | 6 | 7 | 10 | 0.010 | 0.300 | 1.000 | 1.000 | 3.000 |
| Structure | 1 | 2 | 3 | 3 | 2 | 4 | 5 | 2 | 6 | 7 | 10 | 0.010 | 0.300 | 1.000 | 1.000 | 3.000 |
| Battery | 1 | 2 | 1 | 1 | | 1 | 3 | 2 | 1 | | 8 | 0.016 | 0.625 | 1.000 | 1.000 | 5.000 |
| Transducer wheel | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 10 | 0.010 | 0.900 | 1.000 | 1.000 | 9.000 |
| Shutter / Spring | 1 | 2 | 2 | 3 | 2 | 4 | 5 | 2 | 6 | 4 | 10 | 0.010 | 0.400 | 1.000 | 1.000 | 4.000 |
| Shutter Release | 1 | 2 | 1 | 1 | 3 | 1 | 4 | 2 | 5 | 1 | 10 | 0.010 | 0.500 | 1.000 | 1.000 | 5.000 |
| Operation Shaft | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 10 | 0.010 | 0.800 | 1.000 | 1.000 | 8.000 |
| Shutter Release Spring | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 10 | 0.010 | 0.800 | 1.000 | 1.000 | 8.000 |
| Film Reel | 1 | 2 | 3 | 1 | 4 | 1 | | 4 | 5 | 6 | 9 | 0.012 | 0.333 | 1.000 | 1.000 | 3.000 |
| Advance Wheel | 1 | 2 | 1 | 1 | 3 | 1 | 4 | 2 | 5 | 6 | 10 | 0.010 | 0.400 | 1.000 | 1.000 | 4.000 |
| Locking Arm | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 4 | 10 | 0.010 | 0.700 | 1.000 | 1.000 | 7.000 |
| Locking Arm Spring | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 10 | 0.010 | 0.800 | 1.000 | 1.000 | 8.000 |

| | |
|---|---|
| Sum ni*f1i*fi2i*f3i | 83.000 |
| Sum 1/ni^2 | 0.174 |
| Number of non differentiating parts P | 16 |
| Number of products N | 10 |

| PCI | 51.8 |
|---|---|

# ANNEX B

## DATA FOR THE POWER TOOLS

| Function | Camera/components | Contact Plate | Battery | Wire | Clip | Battery Holder |
|---|---|---|---|---|---|---|
| | Diversity for the function | 0% | 50% | 33% | 17% | 0% |
| Provide Power | Screw driver | 2 | 1 | - | 1 | - |
| | Flash light | 3 | 1 | - | - | - |
| | Reciprocating saw | 1 | 2 | 1 | 2 | - |
| | Circular saw | 1 | 2 | 2 | 2 | - |
| | Drill | 1 | 2 | 1 | 3 | 1 |
| | Rotary tool | 4 | 1 | - | 1 | - |
| | | 0.50 | 1.00 | 1.00 | 0.70 | 1.00 |
| Score: 0.84 | | | | | | |

| Function | Camera/components | Motor 60% |
|---|---|---|
| Convert EE-ME | Screw driver | 1 |
| | Flash light | - |
| | Reciprocating saw | 2 |
| | Circular saw | 3 |
| | Drill | 2 |
| | Rotary tool | 4 |
| Score: 1.00 | | 1.00 |

| Function | Camera/components | Switch 67% | Trigger na | Toggle 0% |
|---|---|---|---|---|
| Actuate EE | Screw driver | 1 | 1 | - |
| | Flash light | 2 | 2 | - |
| | Reciprocating saw | 3 | 3 | 1 |
| | Circular saw | 3 | 3 | 2 |
| | Drill | 4 | 4 | 3 |
| | Rotary tool | 5 | 5 | - |
| Score: 0.58 | | 1.00 | 0.75 | 0.00 |

| Function | Camera/components | Gear Train 100% |
|---|---|---|
| Transfer ME | Screw driver | 1 |
| | Flash light | - |
| | Reciprocating saw | 2 |
| | Circular saw | 3 |
| | Drill | 4 |
| | Rotary tool | 5 |
| Score: 1.00 | | 1.00 |

| Function | Camera/components | Light Bulb 100% | Reflector 100% |
|---|---|---|---|
| Convert EE - Light | Screw driver | - | - |
| | Flash light | 1 | 1 |
| | Reciprocating saw | - | - |
| | Circular saw | - | - |
| | Drill | - | - |
| | Rotary tool | - | - |
| Score: 1.00 | | 1.00 | 1.00 |

| Function | Camera/components | Tool Holder 100% |
|---|---|---|
| Import tool | Screw driver | 1 |
| | Flash light | - |
| | Reciprocating saw | 2 |
| | Circular saw | 3 |
| | Drill | 4 |
| | Rotary tool | 5 |
| Score: 1.00 | | 1.00 |

| Function | Camera/components | Housing 100% | Screws 0% | Blade Shield 100% |
|---|---|---|---|---|
| Hold parts and Protect | Screw driver | 1 | 1 | - |
| | Flash light | 2 | - | - |
| | Reciprocating saw | 3 | 2 | - |
| | Circular saw | 4 | 3 | 1 |
| | Drill | 5 | 4 | - |
| | Rotary tool | 6 | 5 | - |
| Score: 0.67 | | 1.00 | 0.00 | 1.00 |

| Function | Camera/components | Guide Plate 100% |
|---|---|---|
| Guide Solid | Screw driver | - |
| | Flash light | - |
| | Reciprocating saw | 1 |
| | Circular saw | 2 |
| | Drill | - |
| | Rotary tool | - |
| Score: 1.00 | | 1.00 |

**TOTAL SCORE 0.87**

## ANNEX C

## DATA FOR THE POWER TOOLS

**Table 11. Improvement proposed to increase the horizontal CDI**

| Function | Versapak | Black and Decker | Firestorm |
|---|---|---|---|
| **Provide Power** | Same *Contact plate* for the Screw driver, Flash light, and Rotary tool; Drill uses the *Clip* of the Saws | Same *Contact plate* except for the Stud finder | Same *Contact plate* except for the screw driver |
| **Convert EE-ME** | - | - | - |
| **Actuate EE** | Same *Trigger* and *Toggle* for the Drill and the Saws | Same *Switch* except the Drill, same *Trigger*, same *Toggle* for the Drill and the Saw, same *Toggle Switch* for the Drill and the Saw | Same *Toggle* for the Saws, same *Switch* for the Saws, same *Trigger* except for Screw driver |
| **Transfer ME** | - | - | - |
| **Convert EE - Light** | - | - | - |
| **Convert EE - Sound** | - | - | - |
| **Import Tool** | - | - | - |
| **Hold Parts and Protect** | Same *Screws* for the Drill and the Saws | - | - |
| **Guide Solid** | - | - | - |